APPENDIX 7-40

TERRATEK SUBSIDENCE STUDY

SUBSIDENCE PREDICTION OVER GENWAL COAL MINE - HUNTINGTON, UTAH

Submitted to:

GENWAL COAL COMPANY
P.O. BOX 1201
Huntington , Utah 84528
United Nations Development Program

Attn: Mr. R. Jay Marshall

TR93-53
March 1993

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Prepared by:

K.P. Sinha

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SUMMARY

Mathematical simulation was conducted to predict potential subsidence induced by active retreat mining operation of Genwal Coal Mine in the Huntington (utah) area. The mining area simulated was the entire Section 36 - Genwal State Lease ML-21569. An integrated approach utilizing finite element method (FEM) as well as boundary element method (BEM) was adopted.

A maximum subsidence of approximately 40 inches is predicted under the crest of south-slope rolling into the Blind Canyon stream near an up-stream section. The subsidence at the stream bed at this section is approximately 35 inches and remains uniform under the north-slope extending almost to 2,000 ft beyond the crest on this side. Thus, the south-slope of the blind canyon stream is somewhat flattened, while the north-slope gradient remains unaltered.

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1 INTRODUCTION

Mathematical simulation was conducted to predict potential subsidence induced by active retreat mining operation of Genwal Coal Mine in the Huntington (utah) area. The mining area simulated was the entire Section 36 - Genwal State Lease ML-21569. **The main purpose of the simulation was to provide input for computing subsidence-induced surface hydrological changes in the Blind Canyon zone in which a stream runs from almost the center of section 36 to the eastern boundary along the 6th left entry.**

An integrated approach utilizing finite element method (FEM) as well as boundary element method (BEM) was adopted. Finite element analysis was conducted using a commercially available program ''ANSYS'', developed and licensed by the Swansi Analysis Systems, Inc., of Houston, Pennsylvania. ANSYS is a well-established, powerful, general-purpose, FEM based code for linear and nonlinear, mechanical and thermal analyses of various kinds of thermal, static and dynamic loading effects.

A computer program ''TABEX-2D'' was used for boundary element analysis. TABEX-2D utilizes displacement discontinuity technique and was developed specifically for design and two-dimensional analysis of mining in seam deposits. This program has evolved from well-established principles and a series of computer programs written by various authors (Sinha, 1979, Crouch, 1983). For a given mining pattern, and a set of values for the seam material and surrounding rock mass mechanical properties, TABEX-2D calculates the seam and off-seam level stresses and deformation.

Several cases were analyzed with varying scenarios related to the stratification and the material properties. It is generally accepted that the overall deformational characteristics in and around a coal mine is well represented by considering that any nonlinear material behavior, if at all, is confined to the seam area and the rock mass in general behaves in a linear elastic fashion. Furthermore, for a conservative, limit analysis, the nonlinear behavior in the mining area can simply be modeled as a linear material behavior characterized by appropriately reduced modulus. Based on this argument, linear elastic treatment with appropriate adjustments to the material properties was considered adequate for the cases analyzed here. Furthermore, two-dimensional analyses reflecting plain-strain situation and involving various cross-sections across the blind canyon stream, was considered adequate for the current purpose.

2 STRATIFICATION and MATERIAL PROPERTIES

The average overburden in the region is approximately 1,500 ft and predominantly consists of sandstone, siltstone and shale. Table 0, Table 1 gives the total thicknesses of these lithological elements in the overburden, as indicated from the borehole logs of the exploratory wells DH-7 and DH-6 located in the north and south ends, respectively, of Section 36.

Table 1 - Overburden Description: Boreholes DH-6 and DH-7

Lithological Description	Total Thicknesses (in ft)	
	Borehole DH-7	Borehole DH-6
Sandstone	1,112	1,050
Siltstone	400	220
Shale	90	114

Based on these values and the actual location of the individual elements, a composite stratigraphy as shown in ?, was built for simulation purposes. The extent of the roof fall and the resulting gob zone thickness, generally varies from three to five times the seam thickness (Peng, 1976). Accordingly, in analyzing the post-retreat mining situation (in FEM analysis), 40 feet of the immediate roof along with the 10 feet of coal seam itself is replaced by gob material. In order to accommodate the uncertainties associated with lithologic variations, various scenarios producing different sets of material properties were used in the analyses. These material property sets are described below.

Table 2 - Composite Stratigraphy for Modeling Purposes

Layer No.	Lithological Description	Thickness (ft)
1	Siltstone	100
2	Sandstone	1,000
3	Shale	100
4	Siltstone	300
5	Sandstone	50
6	Sandstone (Turns into gob material after the retreat mining and roof cave-in)	40
7	Coal	10

Table 3 gives the reference set of material properties assumed for various lithological elements. These material properties, in the rest of this report referred to as *Material Property Set No. 1*, are based on the values reported earlier for the Genwal Mine region (SGI, 1991), and are well within the range of values generally observed for the corresponding rock types.

Table 3 - Elastic Properties of Constituent Materials

Layer No.	Material Type	Young's Modulus (psi)	Poisson's Ratio
1	Sandstone	$3.3x10^6$	.25
2	Siltstone	$6.6x10^6$	.25
3	Shale	$1x10^6$	.25
4	Gob Material (Broken Roof+ left over Coal)	$2x10^4$	.4
5	Intact Coal	$2.5x10^5$	.3

An equivalent set of elastic properties for the overburden represented as a homogeneous medium is obtained using an approximate relationship:

$$\frac{H}{E}=\frac{H_1}{E_1}+\frac{H_2}{E_2}+\frac{H_3}{E_3}+\frac{H_4}{E_4}+\frac{H_5}{E_5} \tag{1}$$

where, H_1, H_2...etc., are the individual strata thicknesses; E_1, E_2...etc., are the corresponding elastic moduli; H is the total overburden thickness, and E represents the equivalent modulus. With the individual strata thicknesses and moduli values given in Tables 1 and 2, we obtain an equivalent modulus value of $3.25x10^6$ psi. Accordingly, the overburden can be represented by an equivalent rock mass Young's Modulus of $3.25x10^6$ psi and Poisson's Ratio of .25. This overburden representation along with the gob and coal properties given in Table 3 forms the *Material Property Set No. 1a.*

The retreat mining operation and the caving of immediate roof in coal mines are known to induce fractures and weaknesses in the overburden. The effective modulus of the overburden is therefore considerably lower than that derived from the laboratory tests on small samples of component layers. Kripakov et al. (1988) found that an equivalent overburden modulus value of 400,000 psi produced results that matched well with the measured stress and deformation values in general. A third set of material properties, *Material Property Set No. 2*, reflecting almost an order of magnitude reduction in the rock mass modulus is given in Table 4.

Table 4 - Material Property Set No. 2 - Equivalent Rock Mass

Layer No.	Material Type	Young's Modulus (psi)	Poisson's Ratio
1	Rock Mass (Overburden)	400,000	.25
4	GGob Material (Broken Roof+ left over Coal)	20,000	.4
5	Intact Coal	250,000	.3

3 PRIMITIVE STRESSES

An average unit weight of 144 lb/cft, giving a uniform gravity loading of 1 psi/ft, has been assumed for the virgin ground (pre-mining situation) in all the finite element analyses. For the boundary element analyses, a slightly higher value of 1.042 psi/ft corresponding to an average unit weight of 150 lb/cft, was assumed for the primitive vertical stress gradient, and the vertical to horizontal stress ratio was taken as 1/3.

4 MODEL DETAILS

The generic models represents a 5,000 ft long vertical cross-sections of the entire Section 36, spanning across the entire Section 36 from north to south main entries and including all the intermediate entries. The mining in the coal seam is represented by 500 ft wide mined-out panels separated by 40 ft wide barrier pillars representing the mining stage in which the retreat mining of all the panels in Section 36 is complete leaving only the barrier pillars between the entries. The overburden, the immediate roof condition, and the gob details are treated differently in different cases analyzed and the type of analysis as described below.

4.1 Finite Element Models

Three cross-sections representing the up-stream, mid-stream and down-stream locations of the stream in the blind canyon were analyzed. The cross sections were constructed from the surface and the coal seam elevation data obtained from the isopatches on the geological map of the area. Figure 1 shows a section of the mine map indicating the locations of the three cross-sections considered in the analysis and Figure 2 shows the cross-sections as modeled. As shown in Figure 2, the Blind Canyon stream is located approximately near the center of the span. Figure 3 shows an example of the full model (up-stream section) with grid details and end constraints.

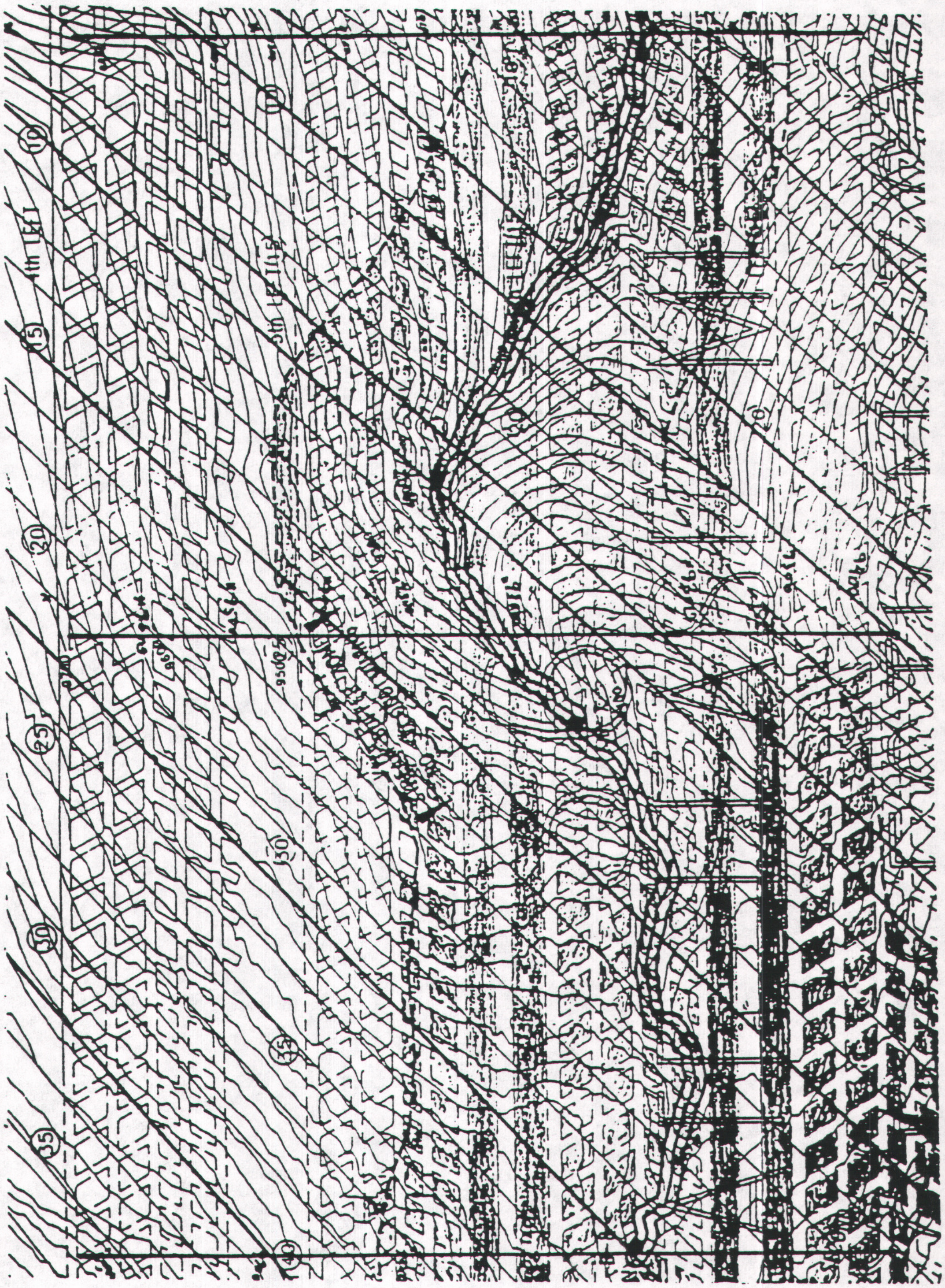

Figure 1 - Partial Mine Map Showing Locations of Cross-Sections Modelled

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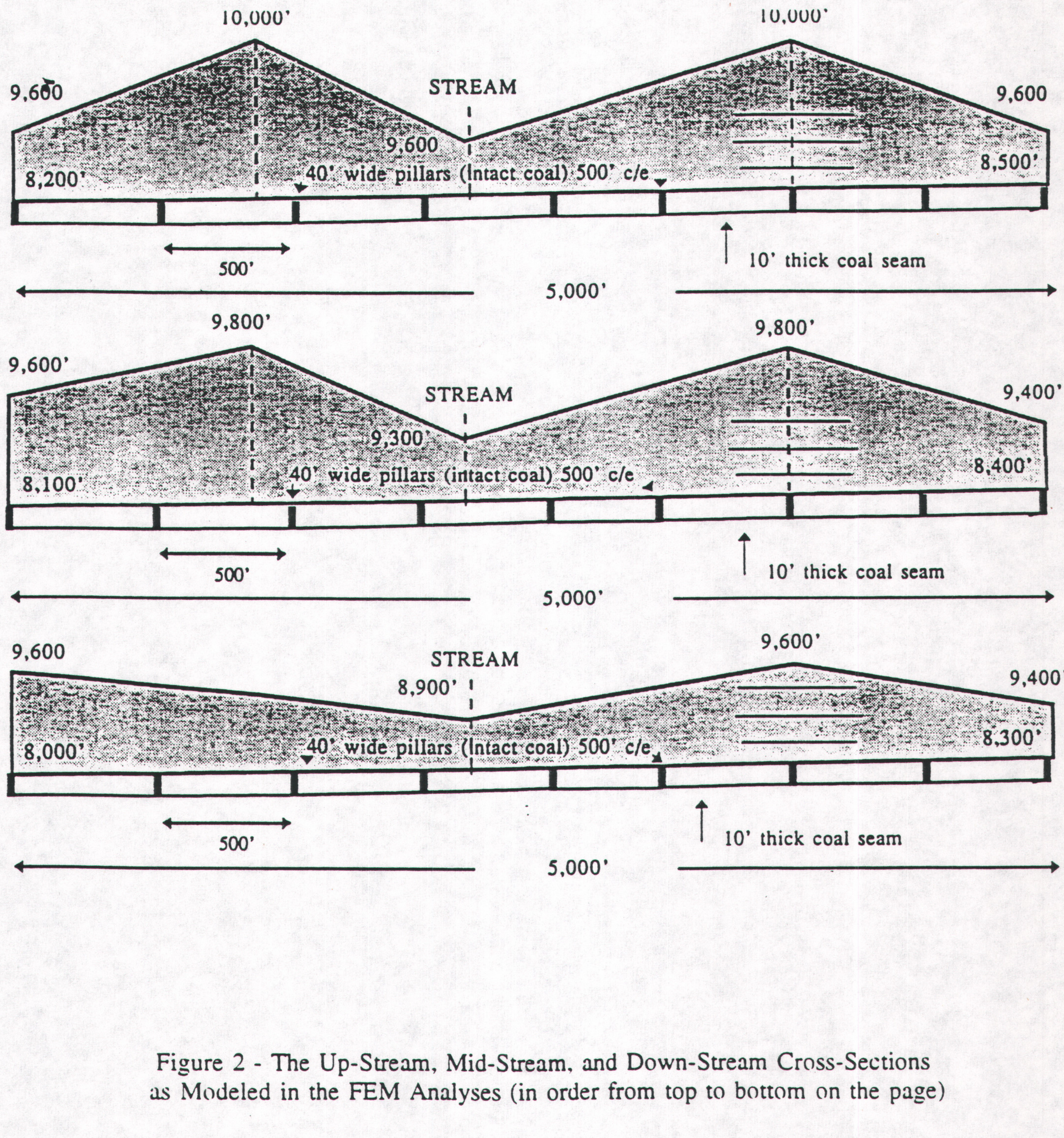

Figure 2 - The Up-Stream, Mid-Stream, and Down-Stream Cross-Sections as Modeled in the FEM Analyses (in order from top to bottom on the page)

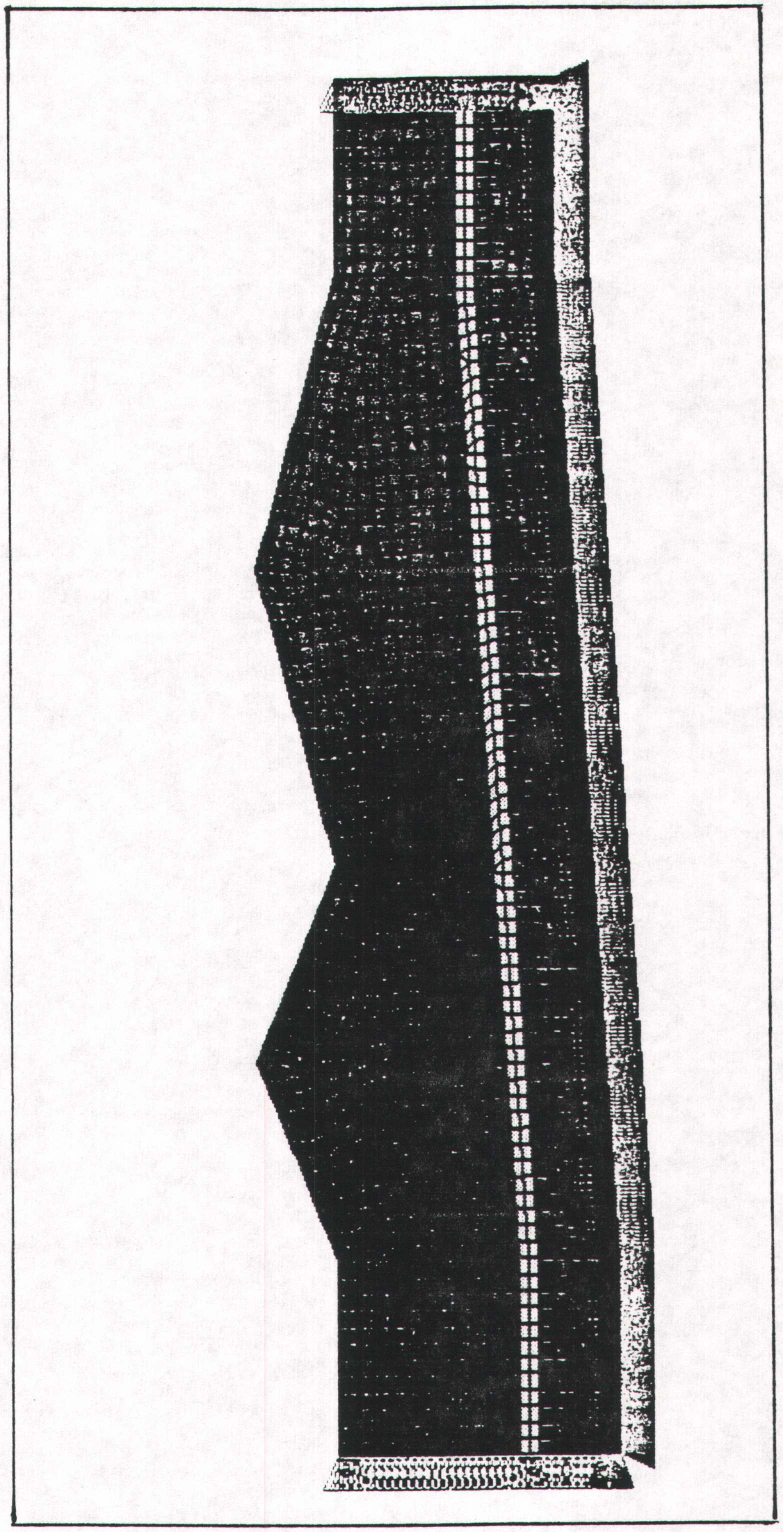

Figure 3 - An Example of the FEM Model (Up-Stream Section) Showing Grid Details and End Constraints

Each of these cross sections were analyzed for the following two cases:

- **FEM Case 1 :** with the overburden treated as stratified rock mass as detailed in Table and the individual strata characterized by Material Property Set 1.

- **FEM Case 2 :** with rock mass treated as a homogeneous medium and the deformational behavior represented by Material Property Set 2.

The analysis for each case consists of a pre-mining run giving the elastic compression of layers due to their weights, and a post-mining run giving the total deformations subsequent to mining. Mining induced subsidence is given as the difference of deformations produced in the two stages. The pre-mining model considers simply the overburden underlain by an intact, 10 ft thick coal layer. The post-retreat mining situation is represented in the FEM analysis by extending the mined panels to 40 ft above the seam and by filling the extended cavities (500 ft wide and 50 ft high), by low-modulus gob material. This arrangement realistically simulates a roof caving above the mined panels and bulking of the broken material. Figure 4 and Figure 5 show a close-up of the full model showing seam-level details for the pre- and post-mining cases analyzed.

4.2 Boundary Element Models

BEM model simulates a flat-lying seam at constant depth below the surface in a homogeneous rock mass. Discretization is required only at seam level and 20 ft wide elements have been considered. Up-stream and down-stream cross-sections as given in Figure 2 were analyzed. The overburden thickness was taken as the average depth of coal seam, at the cross-section being analyzed. *Two different cases were analyzed with Material Property Sets 1a and 2.*

A separate model was created to represent the transverse cross-section of a retreat mined area of the Deer Creek Mine located nearby in similar settings as the Genwal Coal Mine. This mining area was the USBM study-site for a 5-year (1979-1984), subsidence investigation program. Figure 5 shows the mining plan of the area. Very good subsidence record for this study site is available (Allgaier, 1988), and the purpose of analyzing this area was to compare the predicted and measured subsidence values and determine the appropriate model parameters for the Genwal Mine model. *Material Property Set 2 was used for this analysis.*

5 RESULTS AND DISCUSSION

Figures 6, 7, and 8 give the displacement isopatches for the up-stream, mid-stream, and down cross-sections, respectively, as obtained from the FEM analysis using Material Property Set 1 for both the pre- and post-mining stages. The maximum subsidence as indicated from these plots

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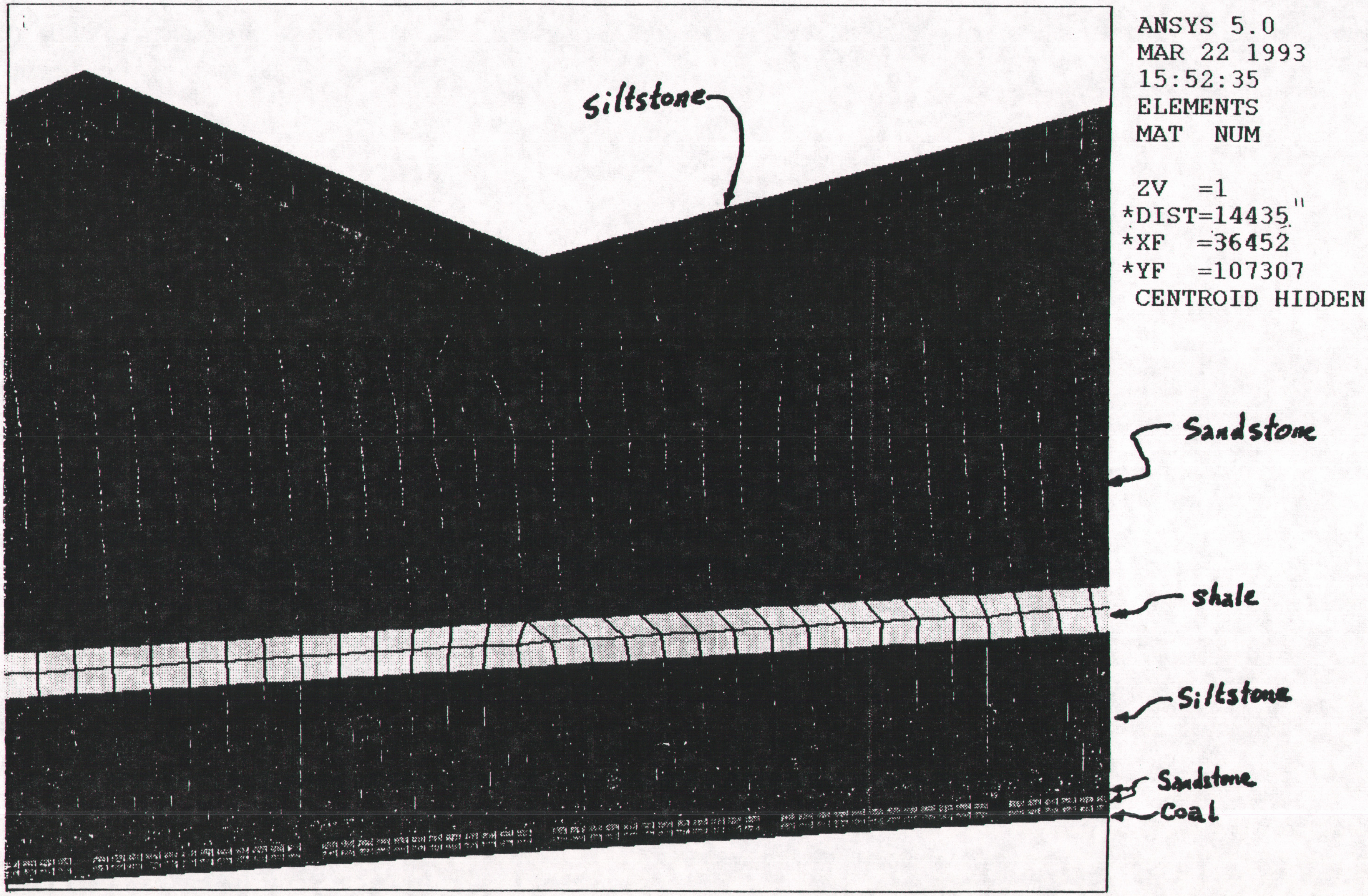

Figure 4 - A Close-Up of the Full Model Showing Seam-Level Details in the Pre-Mining Stage

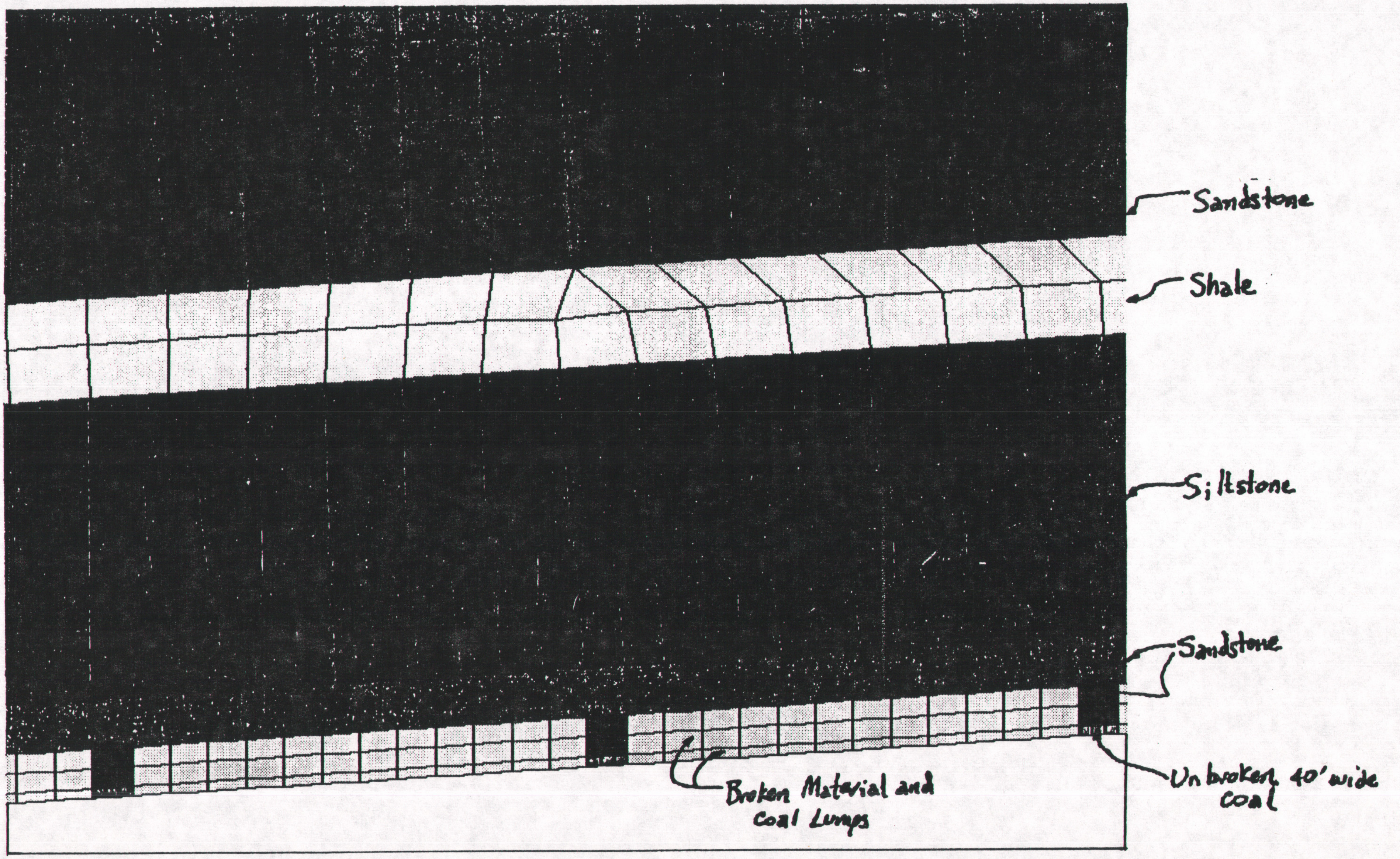

Figure 5 - A Close-Up of the Full Model Showing Seam-Level Details in the Post-Mining Stage

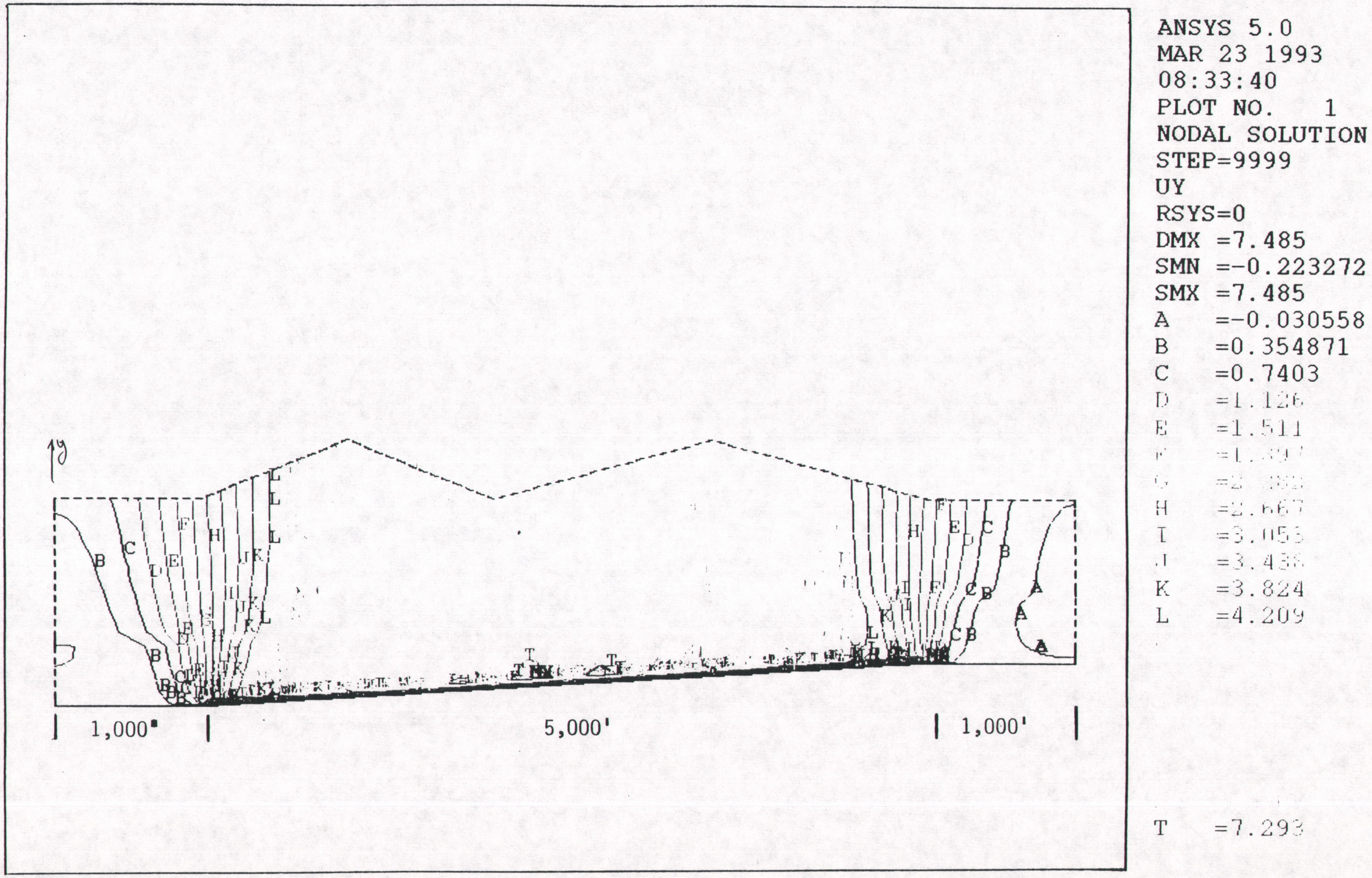

Figure 6 - Displacement Isopatches Giving Surface Subsidence : Up-Stream Section
(FEM Analysis with Material Property Set 1 for Pre- and Post-Mining Runs)

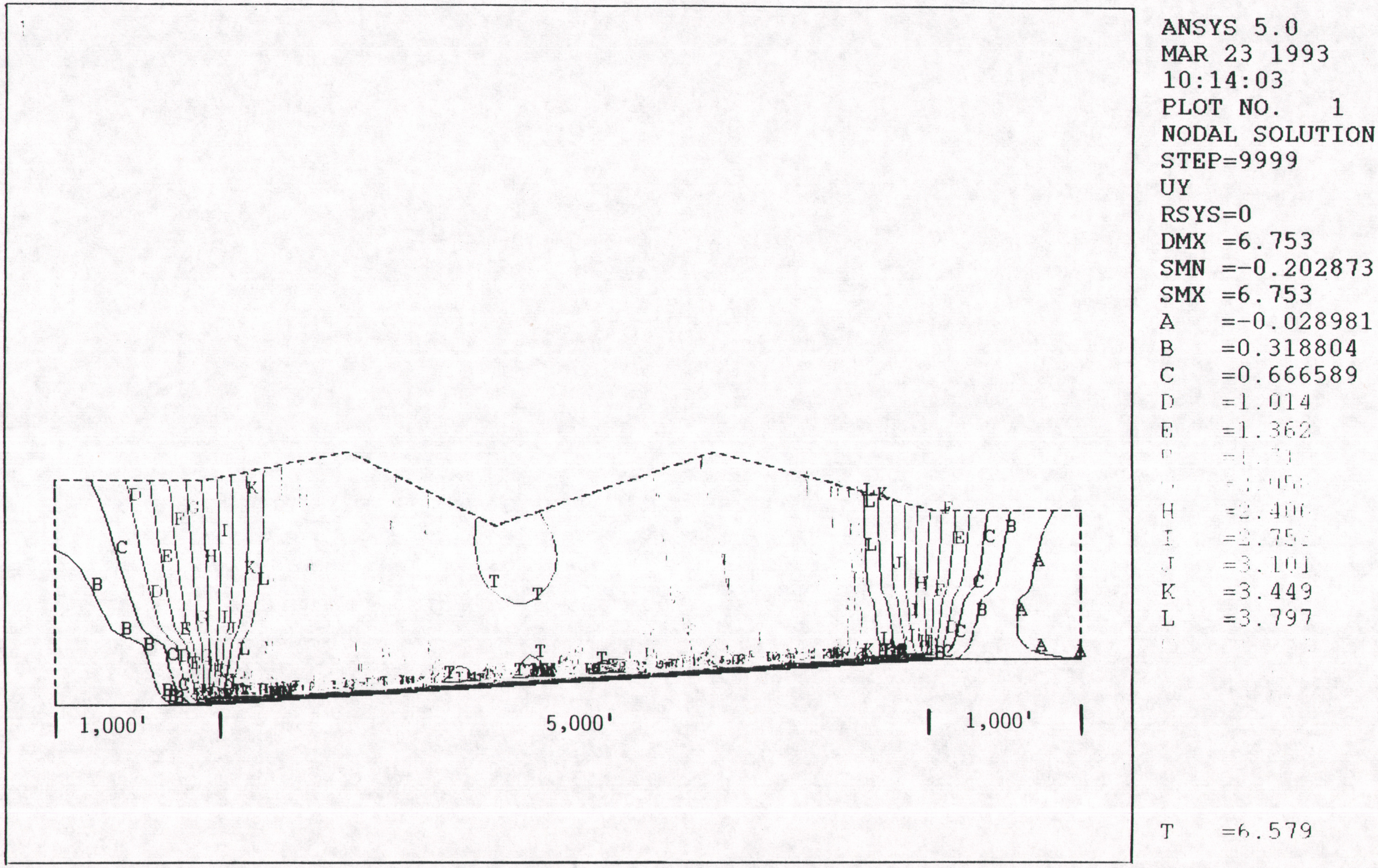

Figure 7 - Displacement Isopatches Giving Surface Subsidence : Mid-Stream Section
(FEM Analysis with Material Property Set 1 for Pre- and Post-Mining Runs)

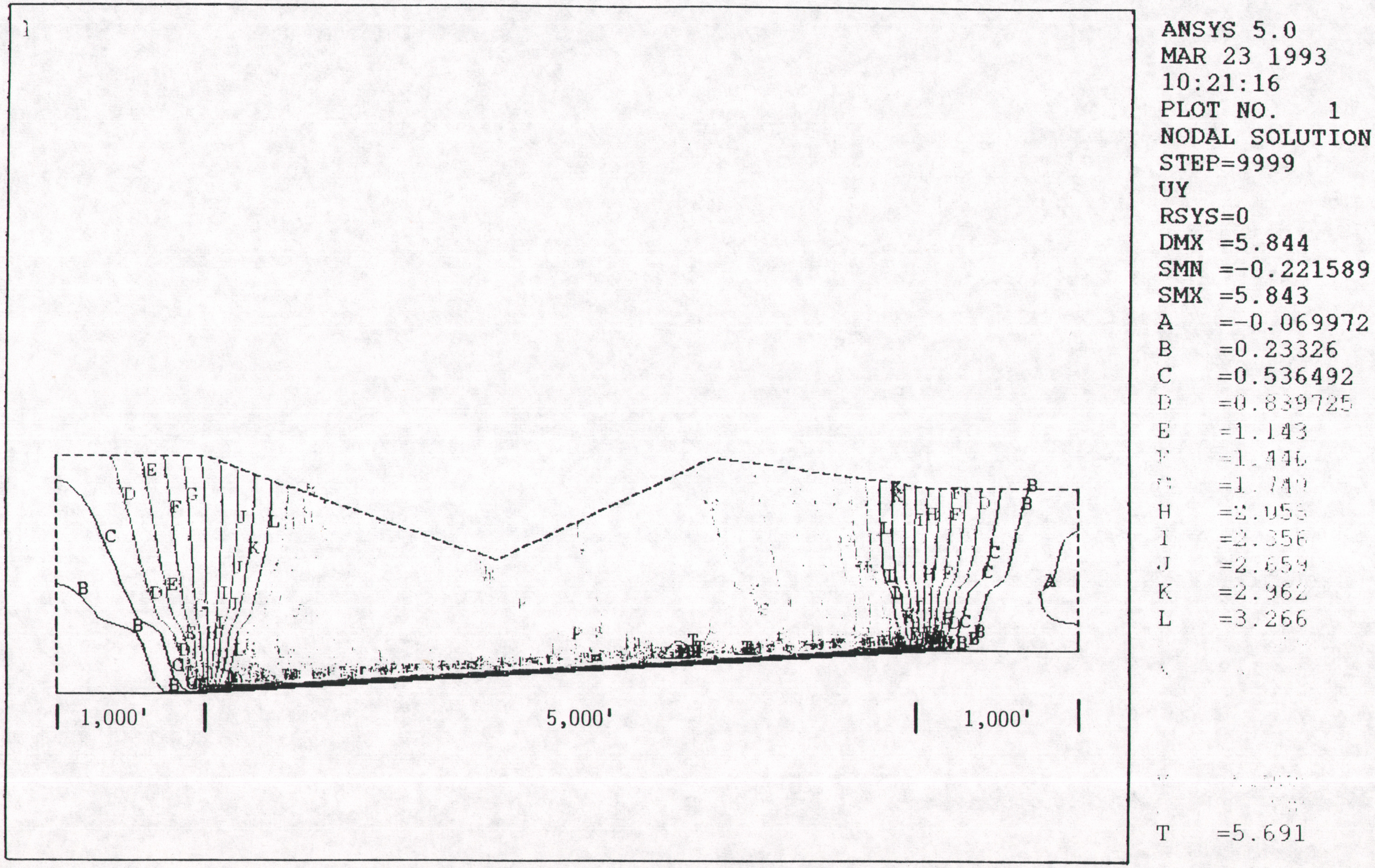

Figure 8 - Displacement Isopatches Giving Surface Subsidence : Down-Stream Section
(FEM Analysis with Material Property Set 1 for Pre- and Post-Mining Runs)

is approximately 7 inches at the up-stream section in the Blind Canyon stream bed. These plots provide a lower bound approximation representing an ideal situation in which the overburden characteristics is not affected by mining.

Figures 9, 10, and 11 give the corresponding results with the weakening of the overburden and an effective reduced rock mass modulus reflected in Material Property Set 2, assumed for the post-mining run. These plots indicate that the maximum subsidence, approximately 40 inches, is still produced at the up-stream section but is shifted towards the crest of south-slope rolling into the Blind Canyon stream. The subsidence at the stream bed at this section is approximately 35 inches and remains uniform under the north-slope extending almost to 2,000 ft beyond the crest on this side. Thus, the south-slope of the blind cannyon stream is somewhat flattened, while the north-slope gradient remains unaltered.

Figure 12 shows the subsidence profile for the up-stream section obtained from the BEM analysis using the Material Property Set 1a, in which an equivalent, homogeneous, and competent rock mass, with elastic modulus of 3.25×10^6 psi, was assumed. As in the FEM Case 1 analysis, this gives a lower bound for subsidence values and is only presented for the reference.

Figure 13 shows the measured and predicted subsidence profiles for the Deer Creek Mine. The predicted profile was obtained from BEM analysis using the Material Property Set 2, but with a low bulking factor for the gob material, such that the gob did not transmit load and offered no resistance to subsidence. The predicted profile agrees well with measured data. This suggests, to an extent, the validity of the assumed material properties and the analysis technique.

Figures 14 and 15 show the Genwal Mine subsidence profiles obtained from BEM analysis using the same approach as used in the validation run for Deer Creek Mine. Maximum subsidence of 5½ ft near the up-stream section and 4½ ft near the down-stream section is predicted.

6 CONCLUSION

In spite of the good agreement between the measured and the BEM predicted results for the Deer Creek Mine, the subsidence over Genwal Mine is likely to be lower than the BEM predictions shown in Figures 14 and 15. The main reasons for this conclusion are given below:

- The exploratory boreholes (DH-6 and DH-7) indicate that 65 to 70% of the overburden at Genwal mine is sandstone with most of it occurring in thick beds, as opposed to the Deer Creek Mine where 45% of the overburden is sandstone with only 35% occurring in thick beds.

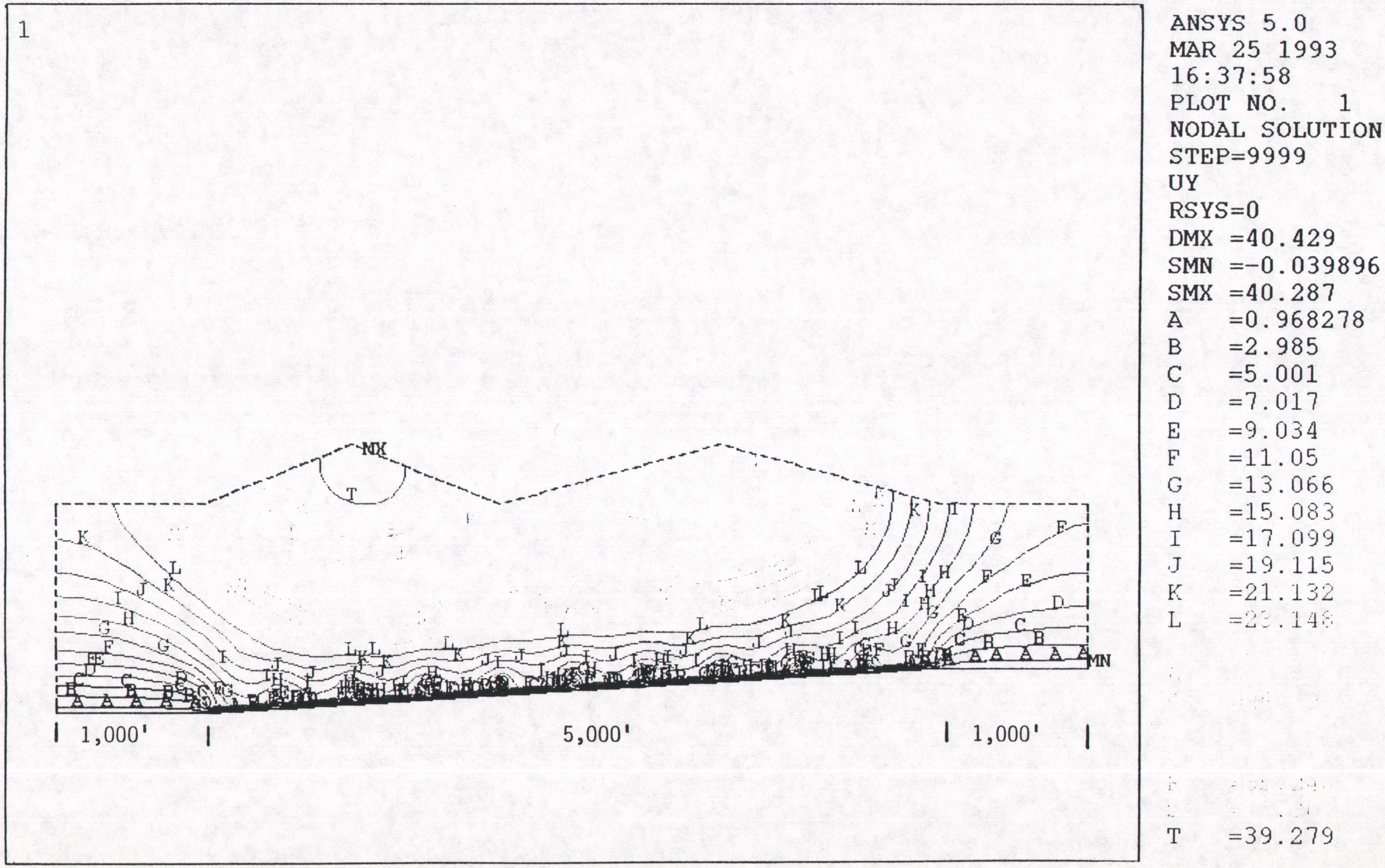

Figure 9 - Displacement Isopatches Giving Surface Subsidence : Up-Stream Section
(FEM Analysis with Material Property, Set 1 for Pre- and Set 2 for Post-Mining Runs)

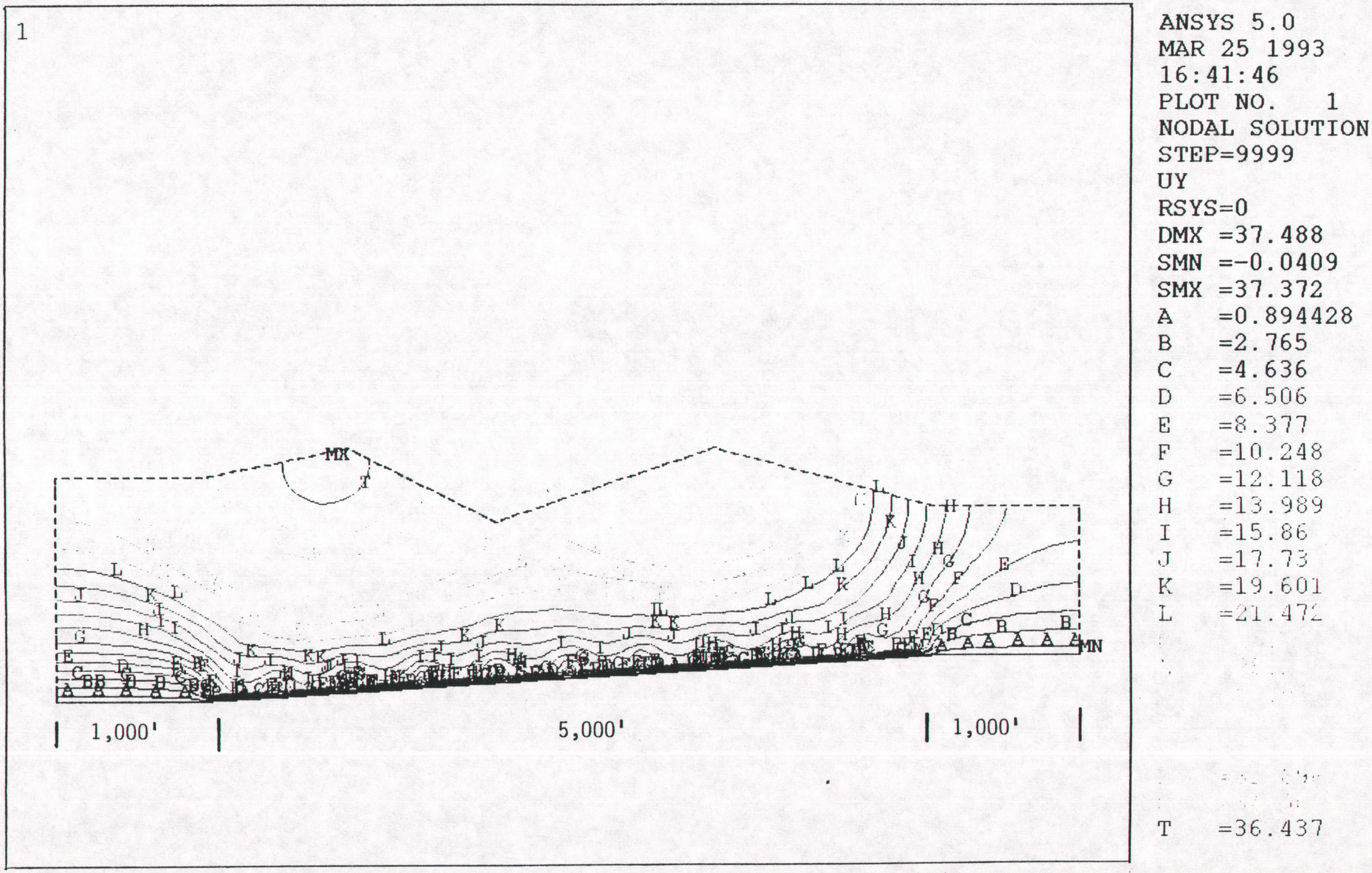

Figure 10 - Displacement Isopatches Giving Surface Subsidence : Mid-Stream Section
(FEM Analysis with Material Property, Set 1 for Pre- and Set 2 for Post-Mining Runs)

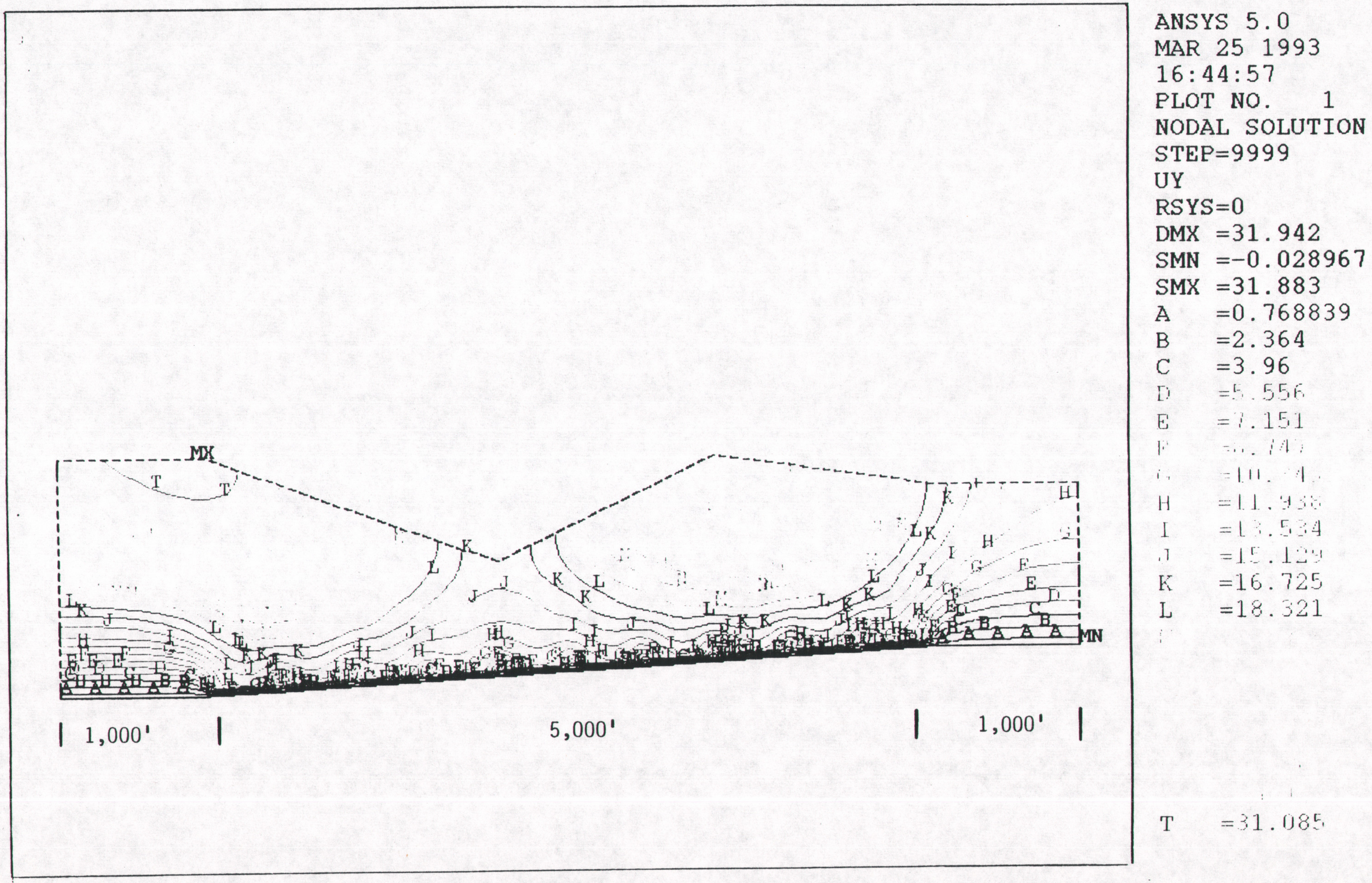

Figure 11 - Displacement Isopatches Giving Surface Subsidence : Down-Stream Section
(FEM Analysis with Material Property, Set 1 for Pre- and Set 2 for Post-Mining Runs)

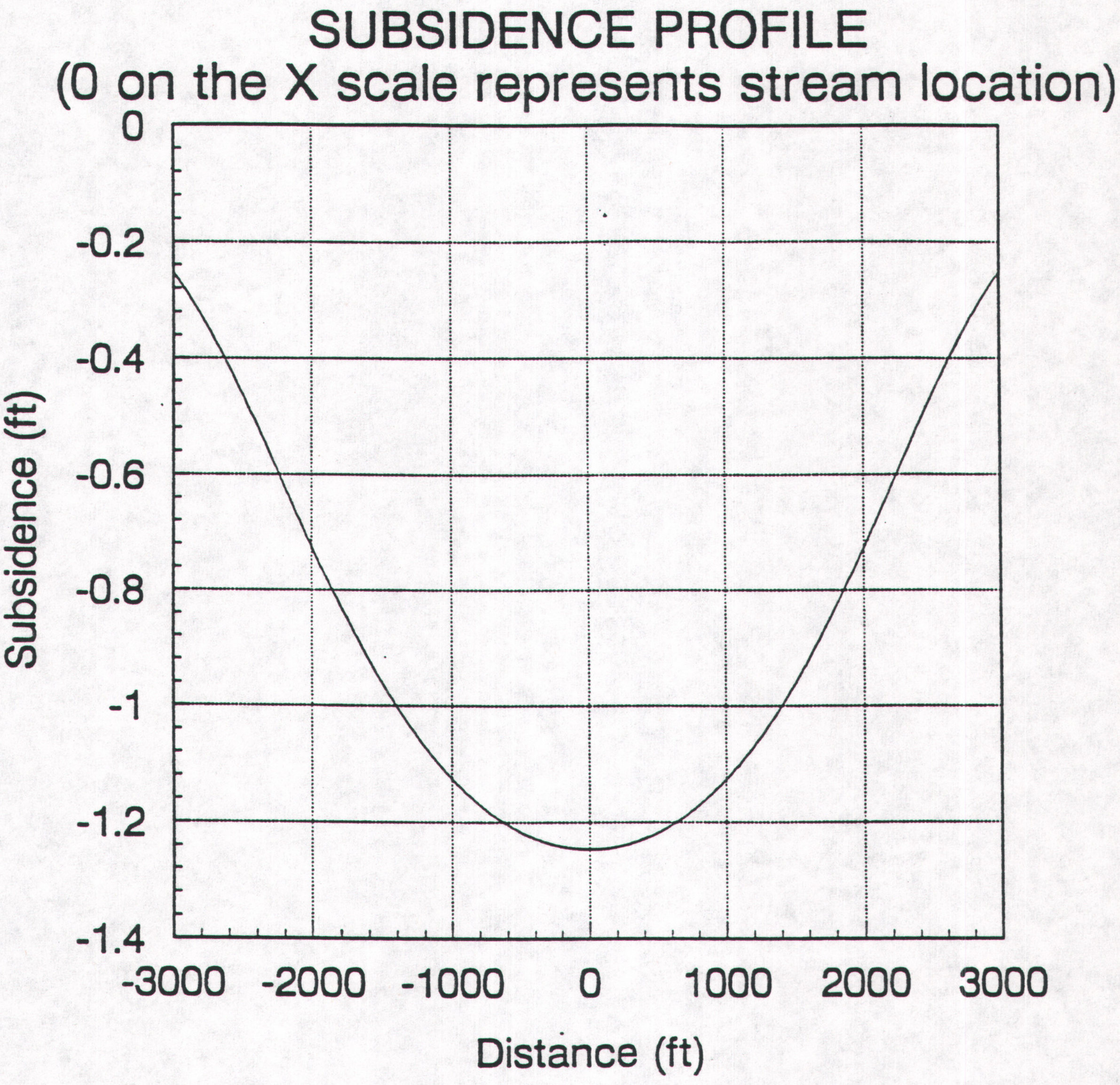

Figure 12 - Subsidence Profile at the Up-Stream Location
(BEM Analysis with Material Property Set 1a)

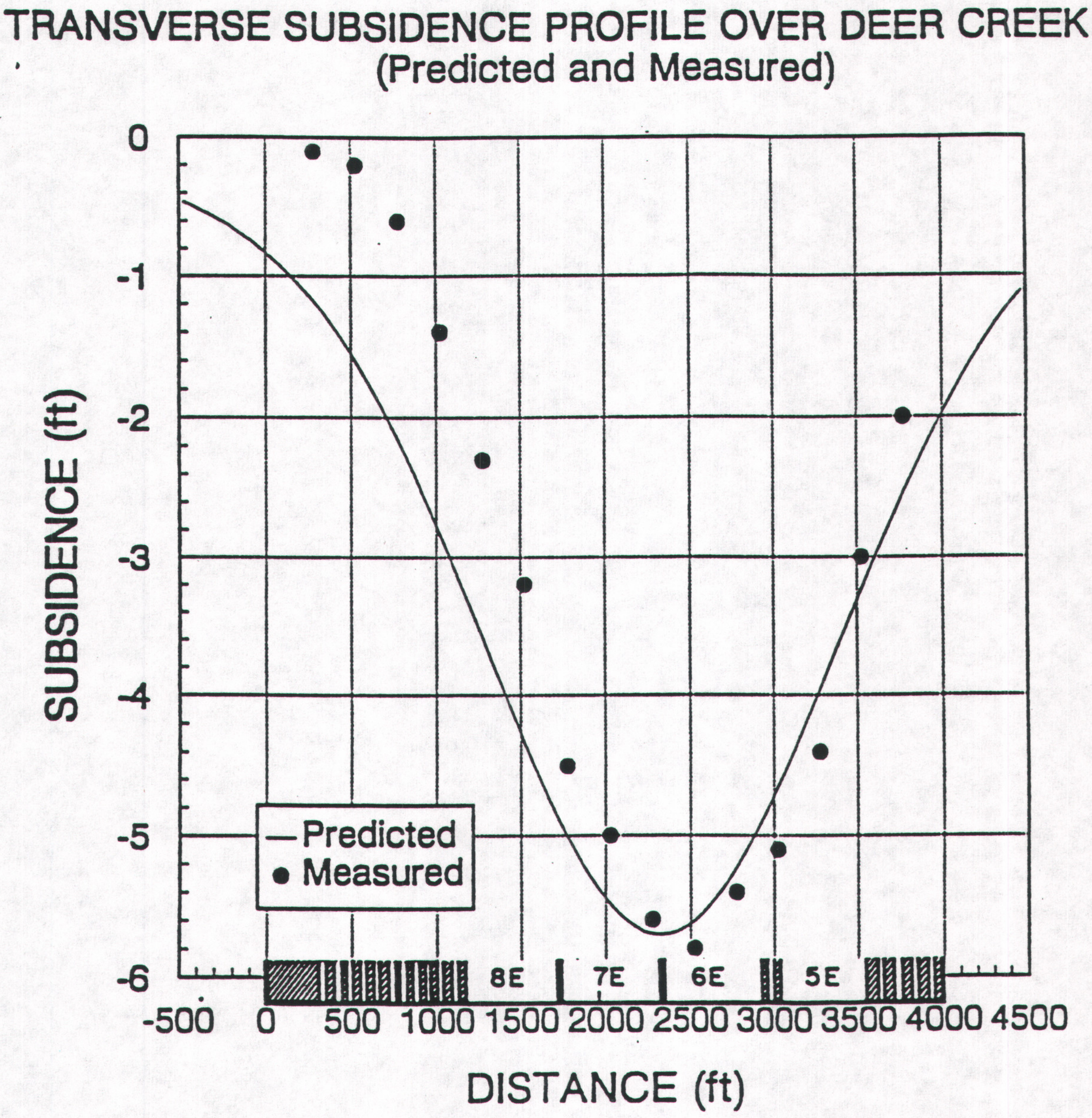

Figure 13 - Subsidence Profile along Transverse Cross-Section Over Deer Creek Mine Study-Site [Predicted profile from BEM Analysis with Material Property Set 2 and Measured Data from Allgaier (1988).]

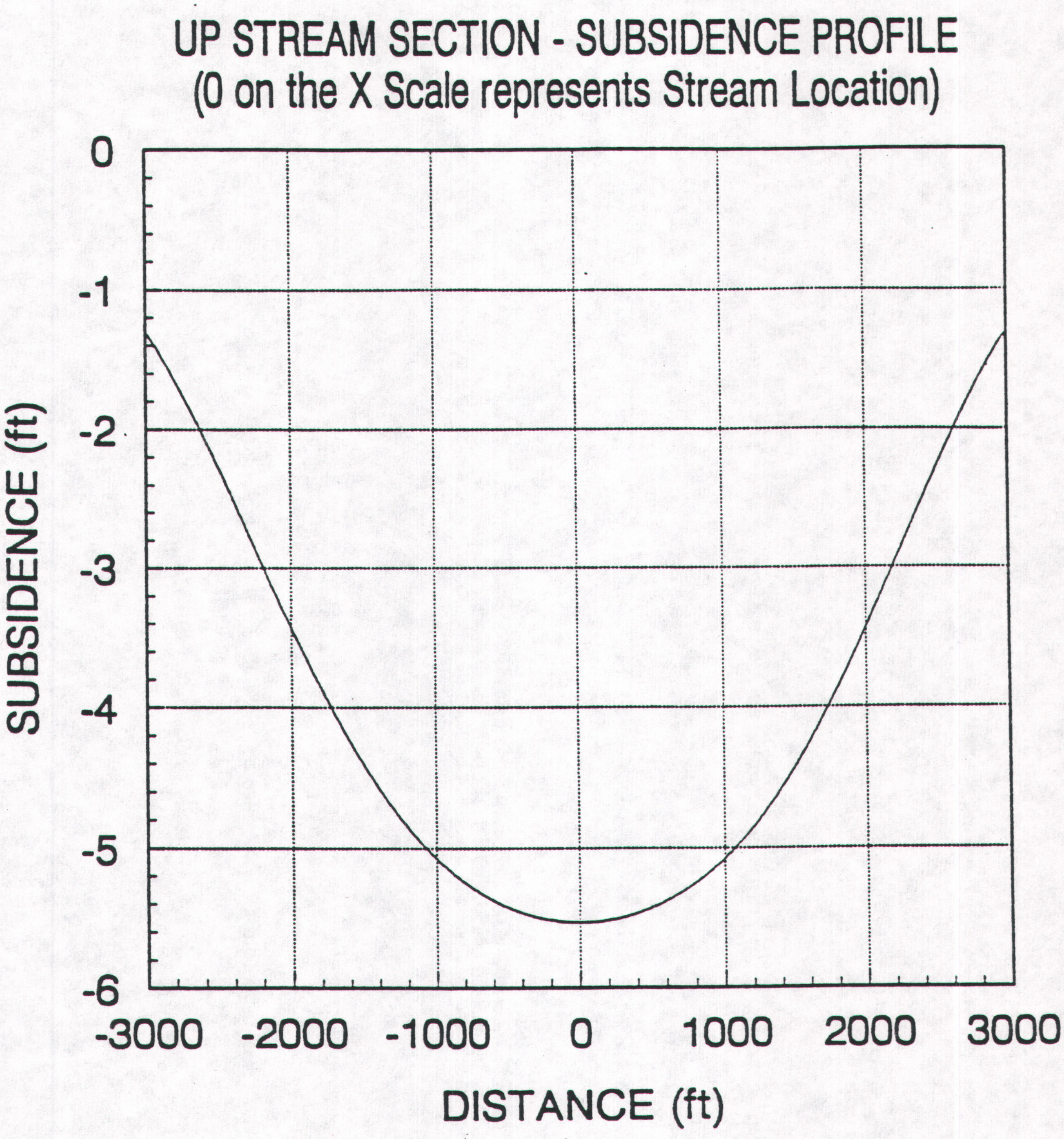

Figure 14 - Subsidence Profile at the Down-Stream Location
(BEM Analysis with Material Property Set 2)

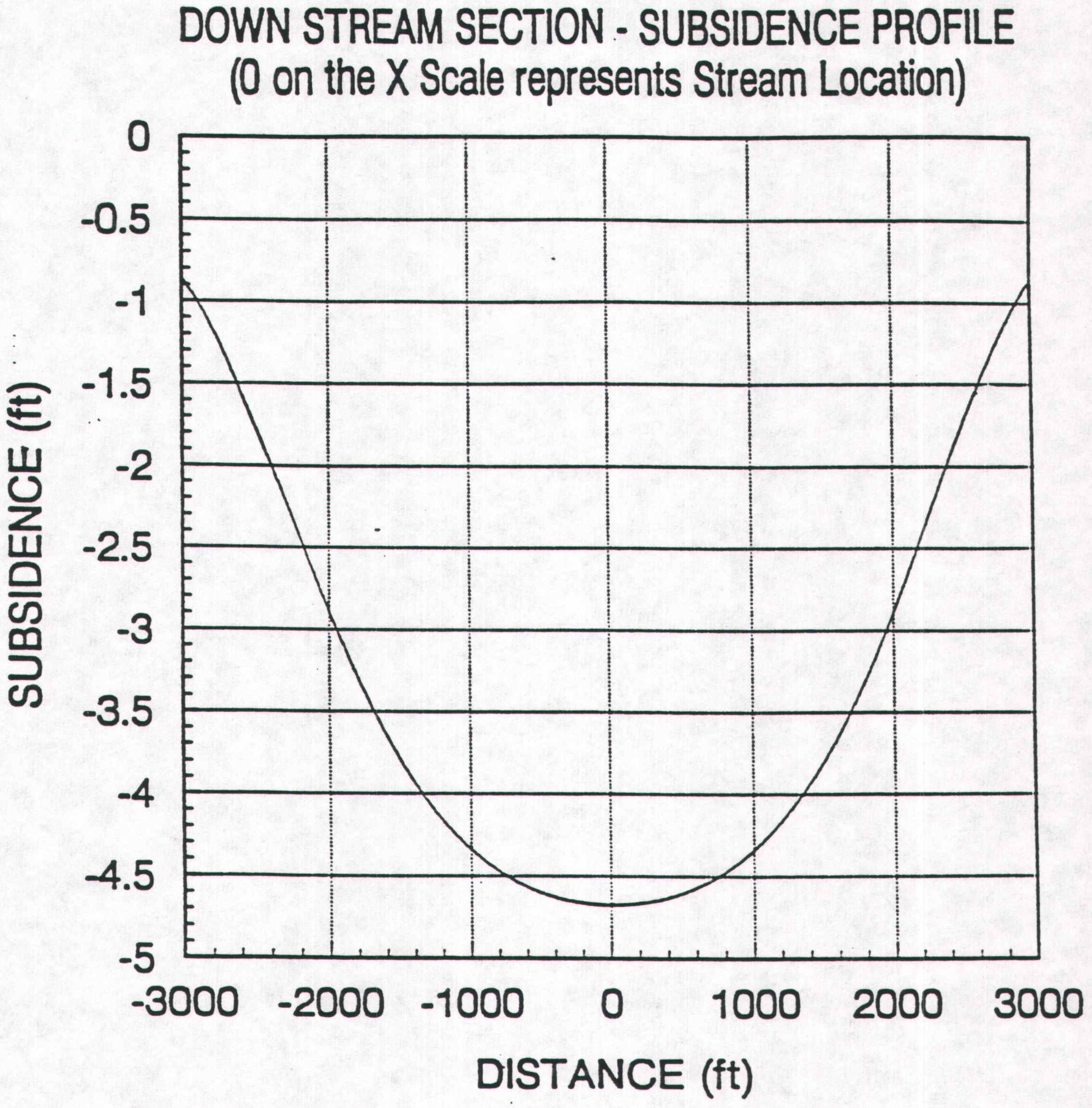

Figure 15 - Subsidence Profile at the Up-Stream Location
(BEM Analysis with Material Property Set 2)

- The extraction in the longwall panels in Deer Creek Mine is 100% while in the room and pillar operation of Genwal Mine, the extraction is not complete, even after the retreat mining.

- Compaction of gob material is likely to increase its modulus as the subsidence takes place offering higher resistance to roof settlement and further subsidence.

It is therefore, recommended that the FEM results as shown in Figures 9, 10, and 11 be accepted. In summary, these plots indicate that the maximum subsidence of approximately 40 inches is produced at the up-stream section under the crest of south-slope rolling into the Blind Canyon stream. The subsidence at the stream bed at this section is approximately 35 inches and remains uniform under the north-slope extending almost to 2,000 ft beyond the crest on this side. Thus, the south-slope of the blind cannyon stream is somewhat flattened, while the north-slope gradient remains unaltered.

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3. Kripakov, N.P., Beckett, L.A., Donato, D.A., and Durr, J.S., 1988, Computer-Assisted Mine Design Procedures for Longwall Mining," Bureau of Mines Report of Investigation, RI-9172,38p.

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